

view of the fact that most of the rainfall in Hawaii is brought about by the forced ascent of the trade winds over the land masses. Another fact, the reason for which is not so evident, is the seesaw relation between pressure and wind movement, and pressure and rainfall. It may be, and probably is, explained by the general principle that high pressure is associated with quiet, clear weather, and low pressure with cloudy, windy weather. Annual temperatures apparently take a course nearly independent of the other elements.

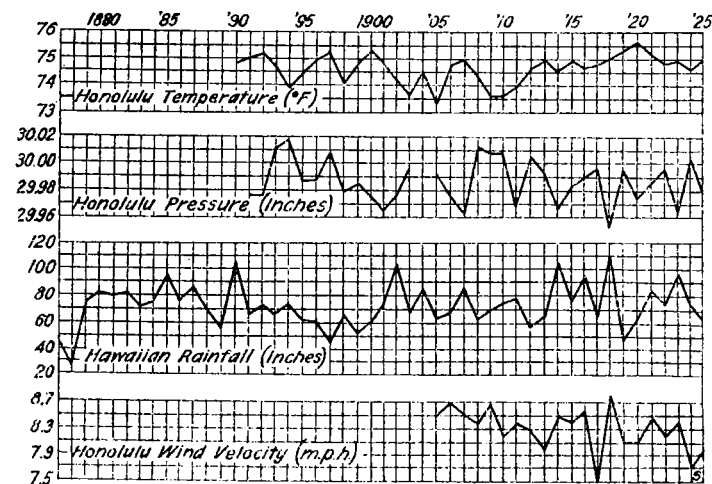


FIG. 1.—Unsmoothed annual values of temperature, pressure, wind velocity, and rainfall (Cox's 10-station average)

CONCLUSIONS

It has been the purpose of this study to show that variations of the weather in the Hawaiian Islands show a systematic tendency, and comparisons were made with the weather elsewhere to show that this tendency was greater than at places in higher latitudes. This, however, could be inferred from what is already known on

FORECASTING PRECIPITATION FROM LOCAL DATA¹

551.578.1 : 551.509

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[Weather Bureau Office, Lansing, Mich., June 10, 1926]

The writer has made a statistical arrangement of the probability of rain following different pressure heights, wind directions, pressure changes, and the several combinations of these factors. The results as presented in the accompanying charts and tables do not show a sufficiently high average of probability to serve their intended purpose as an aid in forecasting. The data are presented, however, in order to show what can be done by this method, and to illustrate the relative importance of the several elements, as they relate to forecasting at this station. Owing to the unsatisfactory results from the forecasting angle, averaging not more than 59 per cent, the discussion will be limited to a brief resumé of the more prominent characteristics revealed by the analysis. There was available a total of approximately 5,450 observations, taken daily at 7 a. m., central standard time, throughout the year, and covering a period of 15 years, 1910 to 1925, inclusive. From these data was calculated the percentage of times precipitation occurred within 24 hours, eliminating from consideration the 12 hours immediately following the observation. This

¹ cf. Chapman, E. H., *Quart. Jour. Roy. Met. Soc.* 42: 289. *Ibid.* 40: 347, the relation between atmospheric pressure and rainfall at Kew and Valencia Observatories. In this paper it is pointed out that the relationship between pressure values and rainfall at a single station is small and vague; that the relation between changes in barometric height is also small, but when dealing with mean pressure values, and rainfall totals a significant relationship is found.—Ed.

the subject. Other facts which are new so far as the writer is aware are as follows:

(1) In the Hawaiian Islands, temperatures show a remarkable tendency to persist.

(2) As regards other meteorological elements such as rainfall, atmospheric pressure, and wind velocity, the persistence is less but still clearly apparent in Hawaii.

A knowledge of the fact that wet and dry weather tend to persist considerably in the summer time might be of some value in long-range forecasting. From May to August wet (wetter than normal) months are followed by wet months, and dry (drier than normal) months are followed by dry months in 73 per cent of the cases for the Hawaiian Islands as a whole. For individual sections this would be somewhat less, depending on the locality.

Periodicities probably have little to do with long periods of abnormal weather, and the cause must be sought for elsewhere. The fact that a persistent tendency is shown in the records of weather in the Hawaiian Islands is sufficient to lend encouragement to those who wish to make further studies on long-range weather forecasting.

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gives the results a comparative value in relation to the results from the synoptic charts. Only the annual probabilities have been given in some instances as it was found that the differences were very slight between the values for the several seasons.

TABLE 1.—Probability of rain with different pressures and different pressure changes, based on 7 a. m. pressure and 12-hour change and rainfall in 24 hours, from 7 p. m., 5,449 observations

	Spring	Summer	Autumn	Winter	Annual
Pressure (inches):					
29.74, less.....	69	52	76	82	73
29.75-84.....	60	44	59	73	59
29.85-94.....	62	49	58	78	61
29.95-04.....	60	48	55	70	58
30.05-14.....	54	49	53	71	56
30.15-24.....	46	36	45	71	50
30.25 over.....	42	34	40	61	48
Total.....	55	46	52	70	56
12-hour pressure change:					
-0.25 inch or more.....	78		76	77	77
-0.24 inch to -0.15.....	71	55	65	81	72
-0.14 inch to -0.05.....	62	56	56	73	63
-0.04 inch to +0.05.....	60	51	56	72	58
+0.06 inch to +0.15.....	45	42	45	64	47
+0.16 inch to +0.25.....	42	34	37	67	46
+0.26 inch and over.....	61		41	62	53
Total.....	50	46	52	70	56

In Table 1 are given the average probabilities of rainfall expressed in percentages, following the several 7 a. m. observed sea-level pressure readings. In general the higher the pressure the lower the probability of rain. During the summer months when precipitation is least, the percentage of times when rain may be expected is better than 50 only when the pressure is under 29.75 inches. During the winter period the probability averages above 70 per cent for all observations, with a minimum of 61 per cent for lowest pressure and a maximum of 82 per cent where readings are above 30.25 inches. The winter probabilities are in excess of what would be expected, based upon the normal rainfall for the season, and are evidently due to the greater daily frequency of precipitation, often amounting to only a trace (too small to measure). Taking the data as a whole it is found that there is a slightly better than 50 per cent chance of rainfall where the pressure is 30.14 inches or less, except during the summer period of normally light precipitation. On this basis, if we were to make a blanket forecast, so to speak, in which rain is predicted for all cases where the pressure falls below 30.14 and *fair* for all cases where it is above 30.14 inches, the resulting verifying average would be about 55 per cent.

The lower part of Table 1 gives the probabilities based upon the 12-hour pressure change. The annual probability of rain following a fall in pressure of 0.25 or more is somewhat higher than that following pressure readings under 29.75 inches. In other words a considerable fall in pressure in 12 hours is a slightly more favorable indication of rain than is a very low pressure reading considered separately. Where the pressure change is minus, even though a small one, the chance of precipitation following within 24 hours is better than 1 to 1 in all seasons. The "blanket" forecast referred to above, however, fails to show a verifying average of more than 56 per cent. A 12-hour rise in pressure of 0.26 inch or more, during the spring months is followed by rainfall more than 51 per cent of the time. This percentage, while almost on the border line, marks a sharp increase in probability over the groups representing a rise be-

is favorable for rain while rising pressure is less so. These conclusions, while not by any means new in themselves, are given mathematical verification by the results in the table.

In Figure 1 the simultaneous consideration of pressure and pressure change as related to the 24-hour rainfall is shown. The greatest probability occurs when there is a 12-hour pressure change of -0.25 and a sea-level reading of 29.84 inches or less. Two secondary maximum probabilities occur, one with a minus change of 0.25 with the pressure over 30.15 inches, the other where there is a plus change of 0.25 inch and an observed reading under 29.75 inches. The least probability is found with pressure 30.25 inches or more with a plus change of 0.25 inch or more. Computing the verifying average by making a forecast of rain for all cases where the probability is over 50 per cent and of *fair* in all other cases, a resulting average of 59 per cent is obtained, or several points better than where forecasts are made in which the two elements are considered separately. In this connection we find similar investigations of the probability of rain as a function of two elements as made by Blair² who in turn refers to studies made by Besson on the same subject. Blair found that the verifying average following this method and using the data for Dubuque, Iowa, was 62 per cent. Quoting his remarks in this connection: "This is only slightly better than the 59 per cent in Table 5 (each element considered separately) and corresponds to the experience of Besson, who says that contrary to expectations the two element combinations do not offer much superiority over the results with one element. However, he constructs eight such figures, giving eight combinations of two elements each, and according as the arithmetical mean of the eight probabilities shown is above 0.50, forecasts rain or no rain, and obtains a verification of 73 per cent for 943 cases."

In Table 2 is given the relationship of the different wind directions to the rainfall within the following 24 hours, using as in the other instances cited thus far, the 7 a. m. observation and eliminating from consideration any precipitation occurring during the 12 hours immediately following the observation. Southeast winds give the most favorable indication of unsettled conditions to follow. Rain occurred in 71 per cent of all cases after an observation of this wind. East and south winds also show better than 60 per cent. The least favorable direction from the standpoint of precipitation is north, which averages only 39 per cent. A forecast of rain or fair according as the average exceeds 50 per cent results in a verifying percentage of 59. North and northwest are the only directions showing less than 50 per cent precipitation probabilities.

TABLE 2.—Probability of rain within 24 hours, with wind from different directions (R 24 equals number of occurrences of rain within 24 hours; P 24 expresses the same in percentage)

Direction	R 24	Total	P 24
North.....	208	528	39
Northeast.....	248	520	48
East.....	279	447	62
Southeast.....	400	567	71
South.....	474	725	65
Southwest.....	712	1,260	56
West.....	331	565	56
Northwest.....	356	744	48
Total.....	3,008	5,386	56
Verification.....			59

² Local forecast studies—Winter precipitation, by T. A. Blair, Mo. Wea. Rev. Feb. 1924-52: 79-85.

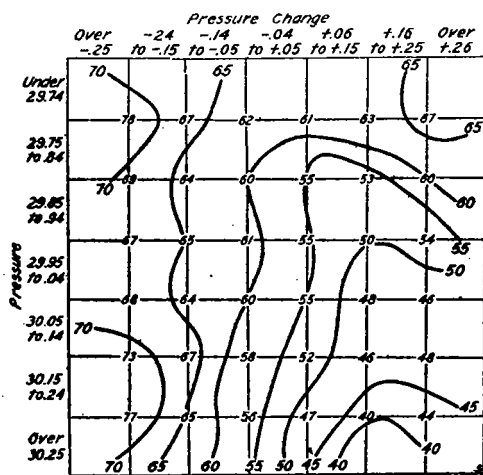


FIG. 1.—Rain probability as a function of pressure and pressure change—data of 5,466 observations

tween 0.06 and 0.25 inch. The rapid movement of high and low areas at this season gives to the plus pressure change where it is a sharp one, a forecast value for approaching unsettled weather. Taken as a whole it may be said that either falling pressure or a rapid rise

In Figure 2 and Table 3 the rainfall probabilities are shown as a function of wind direction and pressure height. In this arrangement the maximum probability is found with a southeast wind and pressure under 29.74 inches, giving an average of 92 per cent over the 15-year period. Southeast winds with pressure 29.84 inches or less are a better indication of rain than south winds with pressure under 29.74 inches. They are almost as

TABLE 3.—Rainfall percentages resulting from the simultaneous consideration of two meteorological elements, based on 5,386 observations at Lansing, Mich. Precipitation of trace or more within 24 hours

Other element	Pressure						
	29.74 or less	29.75-29.84	29.85-29.94	29.95-30.04	30.05-30.14	30.15-30.24	30.25 or over
Wind direction:							
North	75	56	49	35	29	42	36
Northeast	71	64	59	49	43	40	42
East	82	73	74	71	59	58	54
Southeast	92	79	75	67	67	70	60
South	76	71	66	66	69	55	54
Southwest	70	52	62	58	58	48	47
West	67	63	48	54	63	57	40
Northwest	61	44	53	49	48	36	45
Wind velocity, miles per hour:							
0-4	60	56	61	51	52	47	29
5-9	78	60	62	60	61	54	53
10-over	67	52	61	64	61	51	68

favorable a sign with pressure 29.94 inches or less as south winds with 29.74 inches or less pressure. As between forecasting rain for southeast winds or for pressure under 29.74, the average probability favors the pressure element, which gives a percentage of 73 as compared with 71 for southeast winds. Least favorable conditions for rain as shown by these figures are northerly winds with the pressure over 30.05 inches. Wind-velocity averages would seem to show a greater probability for rain with increase. Least favorable are velocities under five miles, although not in every instance. The greatest probability occurs with pressure under 29.74 inches and velocity between 5 and 9 miles. The

results are not consistent, taken as a whole, however. They also fail to agree with the conclusions drawn by Blair from results obtained at Dubuque, where it was found that the greatest probability occurred with the lightest wind movement. Comparison with Blair's figures, however, does not give a true relationship, as he

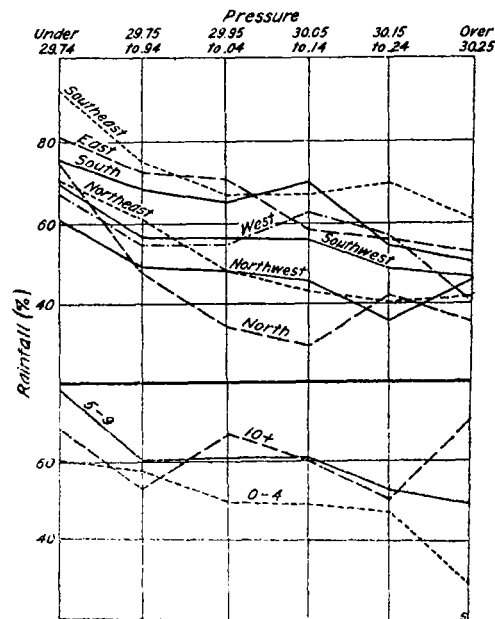


FIG. 2.—Rainfall percentages resulting from the simultaneous consideration of two meteorological elements—wind direction, wind velocity and pressure height

has considered a 24-hour rainfall period beginning with the time of the observation of the several elements or 12 hours earlier than the rain period considered in the present paper. This would seem to explain, too, the results obtained from his investigation, as it moves the time of the observed rainfall nearer to the time of the wind observation, with the accompanying more or less calm conditions of the storm's central area. Figure 2 gives a graphical story of the results described.

WIND AS MOTIVE POWER FOR ELECTRICAL GENERATORS

551.55 : 621.313

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The main reason why wind-driven electrical generators have not come into general use for rural homes is, probably, the hesitancy of the prospective purchaser to depend upon the capricious wind. He knows in a vague way that there are periods of low wind movement and his lack of information on the subject causes him to doubt the success of a generator so operated.

In order to meet the constantly growing demand for an economical and efficient plant of this type, scientists at the College of Agriculture, University of Nebraska, have been experimenting for several years. They have found that a wind velocity of nearly 10 miles per hour is necessary to charge batteries, the wind wheel being exposed at an elevation of 60 feet. This minimum velocity agrees quite closely with the results of experiments carried on at other places.

In view of this requirement, it is interesting to know how much of the time a 10-mile wind may be expected. What per cent of the time will the wind be too light? How often do these periods of low wind movement occur? What is their average and extreme duration? During

what part of the year and of the day are they most frequent? These are vital questions, and while the data may not enable us to foretell the behavior of the wind on a definite day, a knowledge of its behavior in times past gives at least its future average values.

The writer has made a study of the Weather Bureau records of wind velocity at Lincoln for the 10 years 1912 to 1921, inclusive. The most important facts are presented in the accompanying tables and charts. By means of such data the experimenter will better understand the requirements for meeting the actual, rather than the theoretical conditions; and the prospective purchaser may intelligently judge for himself the practicability of a wind-power generating plant.

All measurements were made by a Robinson cup anemometer, the instrument adopted by the U. S. Weather Bureau for measuring wind velocity. The anemometer was exposed above the Brace Physical Laboratory Building on the city campus of the University of Nebraska at Lincoln at a height of 84 feet above the ground.